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AN APPROACH TO THE MEASUREMENT OF THE SHORT
TERM READINESS OF MILITARY SYSTEMS

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Readiness of Military Systems

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    Resource requirements are determined for an individual mission by a transformation of the mission statement to a quantitative basis. This results in the specification of a set of outset requirements. This ability is measured through the use of "mission response functions" which may be approximated by certain types of production functions used in the economic theory of the firm. The suggested procedure of this paper is to employ, as a working definition of readiness for any single mission, the ratio of expected performance (expressed in terms of the mission response function) to the required performance as expressed in a quantitative "mission performance statement".

    Although a measure of the readiness of the system with respect to a single mission may be obtained by the above procedure, there are a multiplicity of missions to which most systems may have to respond during any time interval. The difficulty encountered when attempting to measure readiness with respect to multiple missions are examined. It is suggested that future readiness research should concern itself more with this very difficult problem.

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DD FORM 1473 (BACK) 1 NOV 65
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ii

An Approach to the Measurement of the Short Term
Readiness of Military Systems

Abstract

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each mission. Once these outputs are stated, the problem is to deter-
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INTRODUCTION

In Technical Report No. 1 [8] of this contract, a production function approach to the measurement of short term readiness of Navy units was suggested. The present paper elaborates on some of the ideas of [8], hopefully presents new insights into the problems of readiness measurement, suggests a specific methodology for the measurement of readiness for a single mission, and suggests possible fruitful lines of future research.

From our reading of the readiness measurement research conducted in the past, it would seem that the bulk of the analytical effort was directed towards measuring the readiness of a particular operational unit of the organization (such as that of a destroyer in the Navy). The approaches taken in such studies ([7], for example) might be characterized as hierarchical ones where the overall readiness of the unit was obtained as a function of the readiness of smaller components of the unit's resources in areas such as personnel, capital equipment, material, and the level of training and proficiency of the personnel in handling the material and using the capital equipment. In these approaches, the overall readiness of the unit is determined by a knowledge of the interaction between the functions of elements of the unit corresponding to various resource categories. Other approaches to readiness measurement of a single unit involve the reporting of deficiencies from standard levels of the various resources. On the basis of the magnitude of the deficiencies and the number of deficiencies occurring in different categories of resources, an overall (summary) rating of readiness is assigned to the unit. This is part of the basis of the Navy FORSTAT reporting

system (see [2] for description of this system). Also most of the past work in readiness measurement has stressed the desirability of a scalar-valued measure although the possibility of a vector-valued measure has also been considered [7].

Closely associated with the problem of readiness measurement in the military arena is that of the measurement of combat effectiveness. A critique of the more common approaches to combat effectiveness estimation of army units, and suggestions for improvement, appears in a paper by Hayward [3]. Two points which seem equally applicable with respect to past work on readiness are the following:

1. The explicit consideration of the adversary or enemy in determining combat effectiveness is usually ignored.

2. The explicit consideration of the environmental conditions under which the system will operate is usually ignored.

3. The explicit consideration of the specific mission of the system is usually ignored.

In other words, Hayward suggests that combat effectiveness depends on the enemy, the environment, and the mission. He suggests that the reason many people feel that combat effectiveness "is a quality that is inherent in the unit and can be determined without reference to external factors," is based on the "more or less unconscious assessment of the unit's chances against a typical or most probable enemy in a typical environment with a typical mission." These remarks are relevant to readiness measurement because, as mentioned before, "readiness" and "combat effectiveness" are closely related areas, and most of the past work on readiness measurement has also not specifically considered the environment or the adversary, and has not made the measurement procedure mission oriented.

READINESS

Readiness, the condition of being ready, has the dictionary definition of "being completely prepared or in fit condition for immediate action or use" [9]. The definition does not state for what actions or uses the entity whose readiness is in question should be prepared, but in military organizations we can assume that they are those which it is called upon to perform because of self-preservation, perceived advantage, or command from a higher authority. The dictionary definition also seems to imply that readiness is a binary valued characteristic — either the entity is completely prepared or it is not.

With regard to military organizations we will assume that the entity in question can represent any operating unit of the organization. For example in the Navy it may be a single ship, a group of ships, or an entire fleet command. We shall also assume that the actions or uses correspond to missions which the unit is ordered to carry out by a higher authority. In addition, we shall drop the binary assumption of the definition and consider that readiness can exist at intermediate levels between the condition of "not ready" and that of "completely ready." If we now take these two conditions as representing the end points of the real line segment in the interval (0,1) we are considering readiness as a scalar valued characteristic. For reasons which have to do with the ultimate uses of a readiness measure including simplicity of presentation, we wish to pursue the concept of scalar values in this paper. Although we do not wish to restrict ourselves to whether the scale must be cardinal or ordinal, this paper will be primarily concerned

with the possibility of developing a cardinal scale. Such a scale,
if meaningful, will obviously be more desirable.

Thus, we are considering our definition of readiness in the
sense of the degree or extent to which the system or subsystem is
prepared to immediately carry out any subset of an initially specified
set of missions which may be assigned to it. Note that the term
"immediately" still appears in our definition. We consider that
readiness can change as a function of time but for any finite time
interval T, over which a set of missions is specified the definition
refers to the ability to successfully complete them. Since many
missions may involve an action or protracted operation over T, our
definition allows the readiness to change during the interval if
our ability for successful completion has been altered. We also
will consider readiness as either a deterministic or stochastic
characteristic of the system. When stochastic variables are involved
we shall attempt to measure the expected values of readiness.

We intend to measure the extent to which any subset of the
initial set of missions can be carried out by assigning a value to
the system associated with having given amounts of various resources
available to it. Since any subset of the complete set of missions
can possibly occur, ranging from no missions to all of them, we must
also decide whether to base our measure of value on the most likely
subset, the "worst possible" subset or some other combination of
mission occurrences. This problem is taken up later, but by no
means solved.

The first part of this paper suggests an approach to determining
the response possible for an individual mission. The ability to

perform a mission is usually considered in terms of how available
resources compare with required levels. If all required resources
are available at levels equal to or greater than that needed, then
we would ordinarily say that the system is at full readiness for
the mission.* Difficulties enter when one or more resources are
at less than required levels. Then, what is the ability of the
system to perform the mission? This question must be answered from
the point of view of operational usefulness. It is not enough to
state only the percentage of resources at less than required level,
or the magnitudes of such deficiencies. What is clearly needed is
something which tells decision makers whether any response to the
mission requirement is possible, and hopefully the degree of such a
response. To repeat, the principal difficulties arise when trying
to assess the degree of system response possible given certain
levels of inadequacy of various resources.

The problem is complicated by the fact that certain resources
may be required by more than one mission. Thus, the decision maker
often has to make allocations which affect readiness, and it becomes
difficult to talk about readiness unless one assumes particular
allocations of resources to missions. One is tempted to become
involved in problems of determining readiness under "optimal"
allocation of resources but this is really premature since the very
definition of any objective function needed to determine optimality

*The question of the domain of resources always needs to be considered.
For example, the resources domain could include the mental attitude
of personnel. Much of what one does depends on what resources we con-
sider to be (1) important, (2) measurable as to magnitudes which a
unit possesses, and (3) measurable in terms of how inadequacies
affect performance.

will depend on the measure of readiness on which we finally settle. The assumption of this paper is that some type of allocation formula is decided upon by decision-makers and that the readiness depends on such allocations. Our problem is to measure the expected performance given the allocations.

WHY MEASURE READINESS?

Before embarking on any discussion of the mathematical properties of any function to measure individual mission readiness, it would seem useful to consider how such a measure might be used by organizations. That is, there is no sense in attempting to obtain a numerical readiness measure unless one can employ the measure to the benefit of the organization. In discussing possible uses we should consider both the possibility of ordinal and cardinal measuring systems. We shall roughly consider an ordinal measurement system as one which can assign a rank ordering of value to a set of different systems states while a cardinal measurement system gives us relative value information for different system states as well as rank ordering information. While at this point it is difficult to elaborate upon all the possible uses of a readiness measure, we shall list below those which to us seem relatively important and which would be possible if a measure existed. They are:

1. If a cardinal measure were available, then a marginal rate of change of readiness (either in a continuous or discrete sense) could be developed to indicate the sensitivity of readiness to changes in the levels of various resources and programs. It would also allow system planners to estimate the potential increase in readiness to

be obtained from any addition of resources to the system, as well as the consequences in terms of readiness of foregoing expenditures in various resource areas.

2. Cardinal measures, if available, can be used as the objective functions for many types of mathematical optimization prob` ms of interest. For example, on a short term basis, the optimal redeployment of resources to meet a set of possible new threats to the system can be thought of in terms of maximizing readiness. On a longer basis, the optimum allocation of funds over a period of years could be determined as a solution to a problem whose objective is the maximization of readiness at the end of the period.*

3. Again, on a long term basis, the readiness of a system will change wirh time as our resources age and as the threats and strategies of adversaries change. If a cardinal measure is available and is time dependent, then we can determine how our system's readines` will deteriorate if research, development, and production of new technologies are not undertaken on a timely basis. Thus, the measure can be used to signal when and where R and D expenditures are most appropriate.

4. Both ordinal and cardinal measures of readiness, arrived at by logical considerations and with clearly stated assumptions and limitations, provides a common framework about which differing points of view on construction, procurement, research and development, personnel policies, etc. can be debated and evaluated. It can be

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*Ordinal measures of readiness are also useful and important in quantitative optimization models. See [4] and [5] for recent examples. Also, [6] employs a cardinal measure similar to that proposed in this paper as an objective function.

used to substitute objectivity rather than hunches and emotions into decisions involving alternatives.

MISSION SPECIFICATION

Critical to the present readiness measurement proposal is the need for mission requirements to be expressed quantitatively. We have tried to consider various types of missions in an organization such as the U. S. Navy with respect to common dimensions which many of them possess. Many mission statements either directly or indirectly do involve common dimensions. These at least include the mission duration and the location or geographical area where the mission is to be performed.* However, because of the qualitative manner in which many missions are ordinarily stated it is often difficult to determine variables against which expected successful or unsuccessful completion can be evaluated. Nevertheless, it does seem possible for one to transform the given statement to another which is operationally useful (and acceptable to the originator of the statement). Although additional investigation of the above comment is important, consider the below military example.

A Navy mission involves the mining of specified enemy ports to prevent the passage of shipping into and out of these ports for a certain period of time. An order creating the mission may be as general as that stated above. In order to determine the readiness

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*In [3] it is suggested that in land combat, the mission specification normally should include three specifications. These are (1) the territory to be gained or held, (2) the latest time by which the objective is to be gained, and (3) the maximum allowable cost of achieving the objective. Only if all three of these requirements are met can the operation be said to result in success.

of the Navy to perform such a mission by the present approach, the statement must be transformed into another quantitative statement (obviously not unique) acceptable to the originator of the order. In the above case an initial quantitative statement might take the form, "The probability of a ship entering or leaving any port unharmed for T days should be less than α," where α is specified and where the term "unharmed" is rigorously defined. Different levels of effectiveness of such missions relate to the fact that due to various levels of availability and functioning of the various resources, different expected results from the attempt to carry out the mission are possible. Thus we have expressed the required output of the mission by a scalar value α, the maximum allowable probability of undamaged ship passage. However, to use the methodology proposed in this paper, it is preferable to express mission performance in terms of quantities or amounts of physical resources. In the present example, the value α could be transformed into M, the minimum number of mines, properly placed, that would give the desired value of α. That is, we could think of a functiona relationship existing between the discrete valued variable "number of mines" and the probability level α. It should be noted that in determining the relationship between α and M, explicit consideration should be given to both the environmental conditions and the enemy. Thus, if pressure mines are used, consideration should be given to the expected number which may be actuated by spurious ocean wave actions. Also, for all types, consideration should be given to enemy sweeping operations and how they will affect this relationship.

The determined minimum number of mines represents the performance

level of the mission which is required. The dropping of one mine represents performance at unit level.

PRODUCTION FUNCTIONS

Once the performance level has been stated in required levels, it is necessary to determine the degree to which the organization can meet these requirements with its allocated levels of resources. After having considered at length various possibilities by which organizational resources are combined or marshalled to meet the requirements of many important types of missions, we feel that the level of output possible through the use of a set of resources can best be described by a "production function" concept discussed below.

In economic theory [1], a production function is used to describe how the maximum output of any production process depends on the values of the input ingredients. Assume such a relation can be represented by the mathematical function $y = F(X_1 ---- X_n)$ where y is the quantity of output resulting from the use of input i at level X_i. These inputs can be labor, physical products, or capital items required in the production process.

Technological production functions are characterized in several well known ways. Since these are also of interest with respect to the mission production function which we are attempting to construct, we shall discuss them. First, there is the question of what happens to the quantity of our output product when all inputs increase in the same proportion. In other words, if kX_i, $i = 1 --- N$, units of input i are used, $k > 0$, how does y change? Economists consider

three possibilities: (1) constant returns to scale, (2) decreasing returns to scale, and (3) increasing returns to scale. If $f(kX_1,----,kX_n) < kf(X_1,----X_n)$ we have the case of decreasing returns. If the above inequality is reversed we have increasing returns, and if the relation is an equality we have constant returns. A production function is called homogeneous if $f(kX_1,----kX_n) = k^j f(X_1,----X_n)$. In the case where $j = 1$, the production function is said to be a linear homogeneous production function with constant returns to scale.

Another aspect of production functions involves the question of substitution of factors. If the function $f(X_1,X_2)$ is continuous in X_1 and X_2, then suppose some level y of output can be achieved through the use of X_1 units of input factor 1 and X_2 units of input factor 2. However, many other combinations of factors 1 and 2 will also produce y units of output. All combinations X_1 and X_2 given by the equation $y = f(X_1,X_2)$ will achieve this result. In other words substitution of X_2 for X_1 is possible. If X_1 were in short supply for some reason, a level of output y could still be obtained by using more of X_2 if additional units of X_2 were available.

With many organizational systems and the need to carry out a mission, substitution among factors is sometimes possible and sometimes not possible, and sometimes partially possible. With the Navy example desdribed before, pressure mines may be substitutable for acoustical mines to some extent if there is a shortage of mines of the second type, but many other resources may not have useable substitutes.

Many of the standard production functions are of the form where

substitution is possible. Some well known ones are the Cobb-Douglas, CES, and the linear production functions [1]. However, there is another type which seems to have a high degree of usefulness in measuring mission output. This is the fixed-proportion production function where substitution is not possible.

In systems such as the United States Navy and many non-military organizations, it seems that many resources (ships, personnel, material, equipment) must be brought together in certain proportions in order to be effective. As an example, assume carrier based aircraft require pilots on a one-to-one basis. If 40 aircraft and 30 pilots are available, only 30 airplanes can be made airborne. If fuel is also considered, say 1000 gallons per aircraft, to perform a mission at unit level,* then 25,000 gallons of fuel available means only 25 such missions can be performed. The above concept can be generalized as follows: Let us assume that the system can perform a mission at varying levels defined on the continuous non-negative real axis.

Let $y_j \geq 0$ = the level at which the jth mission can be performed (assumed continuous)

X_{ij} = the level of resource i allocated to the jth mission

a_{ij} = the level of resource i needed to support the jth mission at unit level

Then from the above discussion $y_j = \underset{i}{\text{Min}} \left(\dfrac{X_{ij}}{a_{ij}} \right)$.

The above is the production function for the jth mission output.

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*Unit level of mission performance refers to the mission requirement statement.

Note that it is a linear homogeneous production function with con-
stant returns to scale, where substitution is _not_ possible.

For example, in the carrier based aircraft example, assume a
unit level of the mission equals the dispatch of one aircraft
adequately armed, to a location to provide defense against enemy
aircraft attacking ground troops. Suppose there are four resources
needed to accomplish this mission - aircraft, pilots, fuel, and
ammunition. The availability of each for the mission (the X_{ij}) are
40 aircraft, 30 pilots, 25,000 gallons of fuel, and 200,000 rounds
of ammunition. Suppose the unit level requirements (the a_{ij}) are
1 plane, 1 pilot, 1000 gallons and 1000 rounds. Then the level at
which the mission can be undertaken is

$$y_j = \text{Min}\left(\frac{40}{1}, \frac{30}{1}, \frac{25,000}{1000}, \frac{200,000}{1000}\right) = 25$$

Suppose the quantitative statement requirement for this single
mission at the location considered is "maintaining a presence of at
least 30 carrier based aircraft daily for the protection of ground
troops." Then we may take the ratio 25/30 = 83% and state that the
readiness of the system to perform this mission is 83%. Naturally,
defining readiness as the scalar valued _ratio_ of possible perfor-
mance to desired performance is not the only possible measure to
use for this single mission. However, it has intuitive appeal,
restricts the interval of values to the closed interval (0,1),
permits comparison of alternate configurations of resources, and
can be used to show how various resource limitations affect perfor-
mance. We shall refer to functions which indicate the level of
possible performance as mission response functions (MRF's). In the

present case, the MRF = 25. The evaluation MRF's form an important part of the present approach to determining individual mission readiness.

Many production functions involve the production of more than one output as a result of the production process. Such cases of "joint" production can be considered by imagining that for each output product there exists a production function $y_j = f_j(X_1 \cdots -X_n)$ so that once the mix of the factors of production is specified, the production of each output product is uniquely determined.

With respect to mission requirement statements, they may often involve multiple objectives. Thus, the statement that a given set of aircraft support ground combat troops with firepower also have the ability to perform surveillance operations might be characterized by two quantitative requirements, both of which involve many common resources. The output of such a mission might best be described by a production function involving joint outputs. For example, if infra-red heat detection equipment is a required part of the surveillance operation and the mission requirement statement reads, "maintain a presence of at least 30 carrier based aircraft daily for the protection of ground troops and a presence of at least 25 aircraft daily with suitable surveillance equipment for surveillance purposes," then certain resources are common to both aspects of the mission. There would now be two production functions involving five resources; the original four plus the infra-red detection equipment. Suppose the a_{i1} and a_{i2} now represent the unit level resource requirements for the first part and the second part of the mission respectively. Suppose $a_{12} = a_{11}$, $a_{22} = a_{21}$, $a_{31} = 1000$ as before

but $a_{32} = 700$. Also $a_{41} = 1000$ as before but $a_{42} = 100$, and $a_{51} = 0$
(no detectors needed for ground support) but $a_{52} = 1$. If there are
no detectors available, then obviously $y_1 = 25$ as before but
$y_2 = 20$. Thus, the second aspect of the mission can be performed
at an 80% level, when the same resources are used for more than one
purpose. This same procedure applies whenever certain resources can
be used simultaneously for different purposes.

ESTIMATING THE MISSION RESPONSE FUNCTION

In this section we wish to suggest some approaches to deter-
mining (a) the mathematical form of the MRF, and (b) the parameters
of the MRF. We are given a mission requirement statement which we
assume has been stated in terms of desired levels of numerically
valued output requirements (number of mines, rounds of shells,
number of missiles or aircraft or ships or men, etc.). Often a
mission statement will involve several output variables of the
above type. We can think of the requirements as being stated in
terms of what we can call "primary resources" which must be delivered
to an appropriate location through the use of other "non-primary"
resources. Thus, the mine laying operation requires, besides the
mines themselves, ships or aircraft, pilots, and mine laying
specialists for the initial delivery, surveillance mechanisms to
determine the deterioration, if any, of the minefield, and additional
mines, ships, aircraft and personnel for replacement purposes during
the interval when the operation is to be effective. In order for
the above ships, aircraft, and personnel to be employed, the
operation would require fuel, maintenance, and other logistics

support for the delivery vehicles and personnel. This three level
hierarchy seems to be typical for many operations – (1) the item
or items to be delivered, (2) the delivery means, and (3) the support
of the means of delivery. Of course in considering the resource
domain any resource whose inadequacy can adversely affect the mission
must be considered.

Now the approach suggested here is to develop functional rela-
tionships, where possible, between resources at the three levels and
have the final form of the MRF expressed in terms of a minimum number
of different resources needed to completely specify it. Then, in the
final form the output is expressed in terms of some items to be
delivered, some delivery resources, and some of the more remote
resources.

Such a "final" set of resources upon which the output depends
will be called the basic of fundamental resource set. The determina-
tion of the MRF in terms of the basic resources constitutes the
desired form of the MRF. For example, if we are considering mines
to be dropped exclusively by aircraft over a specified time period
we might write that

$$N = \text{Min}\left(M, \frac{A}{a_{11}}\right)$$

where

N = the number of mines appropriately planted

M = the number of mines available

A = the number of flights to the target area which
can be launched during the specified time

a_{11} = the number of mines which one aircraft can hold

That is, the number of mines which can be planted is limited either by the number of available mines or the number of flights which can be launched. Furthermore, we might assume that

$$A = \text{Min} \left(\frac{P}{a_{12}}, \frac{F}{a_{22}}, \frac{U}{a_{32}} \right)$$

P = the number of available flight manpower

F = the quantity of available fuel

U = the number of available aircraft

a_{12} = the number of flight manpower required per flight

a_{22} = the quantity of fuel required per flight

a_{32} = the number of aircraft per flight ($a_{32} = 1$)

We are neglecting the need for specific manpower classes in the above. Thus, substituting:

$$N = \text{Min} \left(M, \frac{1}{a_{11}} \left[\text{Min} \left(\frac{P}{a_{12}}, \frac{F}{a_{22}}, \frac{U}{a_{32}} \right) \right] \right)$$

Of course, if we are considering the mission over a time interval, then we would also have to consider the degradation of aircraft and manpower due to breakdowns and similar losses. The number of flights will depend not only on P, F, and U but also on flight losses and the availability of spare parts and trained repair crews. Consider the aircraft degradation problem where all variables are deterministic. Suppose U_1 round trip aircraft flights are possible in the period if no breakdowns or losses occur. Suppose the rate of flight degradation due to breakdowns is a_1 and that due to losses is a_2 ($0 \leq a_j \leq 1$, $j = 1,2$) so that $a_1 U_1$ and $a_2 U_1$ represent the number of flights lost from each cause. Also suppose that the availability

of r spare parts will allow an aircraft that would otherwise break down during the period to be operational. If K spare parts are available, then the number of flights possible is given by:

$$U = [1 - (\alpha_1 + \alpha_2)] \ U_1 + \frac{R}{2r} \quad \text{if} \quad \frac{R}{r} < \alpha_1 U_1$$

$$= U_1 + \frac{\alpha_1 U_1}{2} \quad\quad\quad \text{if} \quad \frac{R}{r} \geq \alpha_1 U_1$$

The above illustration assumes that any aircraft that breaks down can be repaired immediately using the spare parts and that a repaired aircraft will not break down again during the mission. The need for repair crews is not considered and it is assumed that a repaired aircraft can make one-half as many flights as one which did not break down. Lost aircraft cannot be recovered in any manner.

This function would have to be substituted in the previous equation for U. The fundamental resources in the MRF equation are now M, P, F, and R (mines, flight manpower, fuel, and spare parts).

The above example has been used to illustrate one of a variety of ways in which the mission response function involving fundamental resources can be developed. Specific mathematical functions will of course depend on the nature of the missions and how far back it is feasible to carry any relationships.

READINESS CONSIDERATIONS WITH RESPECT TO A SET OF MISSIONS

What we are trying to measure is essentially the "value" to the unit of having the capability to perform each of its missions

at some level of proficiency. The question we must ask is "does this value measure depend on how all the missions are performed, on how the .ost important are performed, on how the most likely are performed, or on performance applied to some other subset of missions?"

Without too much thought it becomes apparent that much will depend on how the missions are related to each other. The performance of certain missions may be affected by successful or unsuccessful performance of others. In this sense, missions may be independent, mutually exclusive, or dependent in some manner. For example, assistance of a ship in sea rescue operations of some sort (one mission) may be independent of the ship acting as a spare parts depot (another mission). Or, a mission "shell enemy shore installations" (one mission) can only be accomplished if (another mission) "move to vicinity of enemy shore" is accomplished first. Furthermore, many aspects of whether certain missions are independent or non-independent often depends on how resources are allocated to missions and to how they are defined.

When a group of missions are to be performed, they also may have to take place in either what may be termed a roughly simultaneous manner or a sequential manner. On a sequential basis there is a possibility of reusing resources or reallocating unused resources from those missions performed first to those performed later. On a simultaneous basis this is not possible. In developing an interaction model, such relations must also be considered.

As mentioned previously, any approach will imply that the overall unit readiness will depend greatly on how the unit in

question allocates or utilizes its resources with respect to its various missions. If the organization decides to spend most of the time of its available manpower training for some one mission at the expense of other potential missions, then we would say that the command is putting the unit into a certain state relative to the potential missions. Our measurement system is merely a device to try to numerically estimate the ability of the unit to react to the missions as a group, given certain assumptions regarding probabilities, importances, and how the missions interact.

The short term readiness problem of any military organization might be compared to that of a general repairman in an industrial setting. The repairman can be called upon at any time to repair a piece of broken-down equipment, or engage in repairs involving carpentry, plumbing, masonry work, and possible other skills. From his experience he has learned something about (1) the likelihood of various types of work he will be summoned to perform and (2) the criticality of some jobs (to the smooth functioning of the enterprise) over others.

In order to meet what is perceived as his job needs, varying amounts and types of certain tools and materials have been made available to him. Given that we know the amounts of materials and an inventory of his tools, as well as his level of skill and ability in various crafts with which he may be involved, how do we measure his potential ability to respond to the calls and make the necessary repairs?

Although the above simplified situation has many similarities to that of military systems, there are also obvious differences.

However, the example can still be instructive in indicating how to proceed with the more complex situation.

Different observers will consider the repairman's readiness to be satisfactory according to different criteria. Many of these will boil down to considerations involving what proportion of the critical jobs he can be expected to perform satisfactorily, where observers will demand proportions ranging from 1.0 downward. Others will want more than just satisfactory performance on critical jobs but will also demand adequate performance on most non-critical jobs.

An examination as to which criteria are preferable will not be undertaken here. Rather, what we should do is to try to suggest several possible approaches and in conjunction with the repairman and his supervisors, arrive at some satisfactory methodology.

From our previous work on individual missions, the mission readiness function is intended to measure the potential performance on a mission and how this compares with the mission requirement. Applied to the repairman, we could now introduce values $\underline{Y}_j$ which constitute what is deemed the minimum of level of satisfactory performance on job j in order for performance to be called "satisfactory." Thus, any job for which $Y_j \geq \underline{Y}_j$ is one which can be performed satisfactorily. The value Y_j in the general readiness context would represent the MRF for mission j and $\underline{Y}_j$ the required performance for the same mission.

Now with the different jobs, the repairman's ability to perform any job, crucial or relatively unimportant, depends to an extent on the frequency with which these jobs arrive. If he becomes overwhelmed with work his ability to perform well will decrease,

principally because certain of his critical resources (himself for example) can only be in one place at one time. Those resources which are essentially required on many jobs can be overwhelmed if jobs come in quickly enough. Thus, we would characterize the repairman's job profile as consisting of job types which use certain common resources. We could set up a job by resource matrix indicating by a "1" in the appropriate cell whether the resource is required by the job in any significant amount (without regard to magnitude). For each resource we could list the number of jobs that require this resource. Such a matrix could be constructed and be useful for any future analysis of mission performance of any organization. In a following paper we would like to use some of the considerations discussed above to formulate some specific approaches to determine readiness in terms of groups of missions.

FUTURE RESEARCH

Future research should concentrate on the multiple mission problem and on questions relating to readiness measurement when a system may be called upon to perform in different ways at the same time using many common resources. This problem is especially important for non-military organizations.

Also, the adequacy of the type of scalar-valued measures suggested in this paper for a single mission should be examined. Is it possible to develop quantitative mission requirement statements for most missions of both military and non-military organizations and is the construction of MRF's a feasible procedure? Only the testing of the above concepts in real environments can provide adequate answers to these questions.

REFERENCES

[1] R.G.D. Allen, Mathematical Economics, St. Martin's Press, New York, 1966.

[2] Steven A. Frank, William B. Gruttke, W. H. Marlow, and Samuel J. Mathis, Jr., "Readiness Measurement Using Subresource C - Ratings," Technical Paper Serial T-216, George Washington University Logistics Research Program (1968).

[3] Philip Hayward, "The Measurement of Combat Effectiveness," Operations Research 16 No. 2, March-April 1968.

[4] Peter J. Kalman, "A Stochastic Constrained Optimal Replacement Model: The Case of Ship Replacement," Operations Research 20, No. 2, March-April 1972.

[5] Seymour Kaplan, "A Note on a Constrained Replacement Model for Ships Subject to Degradations in Utility," Naval Research Logistic Quarterly, Vol. 21, No. 3, September 1974.

[6] Seymour Kaplan, "Application of Programs with Maximum Objective Functions to Problems of Optimal Resource Allocation," Operations Research 22 No. 4, July-August 1974.

[7] Final Report - Material Readiness Index System (MARIS), Contract NO sp 65204-d (FBM), TEMPO, General Electric Company, Santa Barbara, California.

[8] Technical Report No. 1, "A Production Function Approach to the Measurement of Short Term Readiness of Navy Units," New York University, Prepared under Contract N0014-67-A-0467-0028 for the Office of Naval Research (September 1972).

[9] The Random House Dictionary of the English Language, Random House, New York, 1966.